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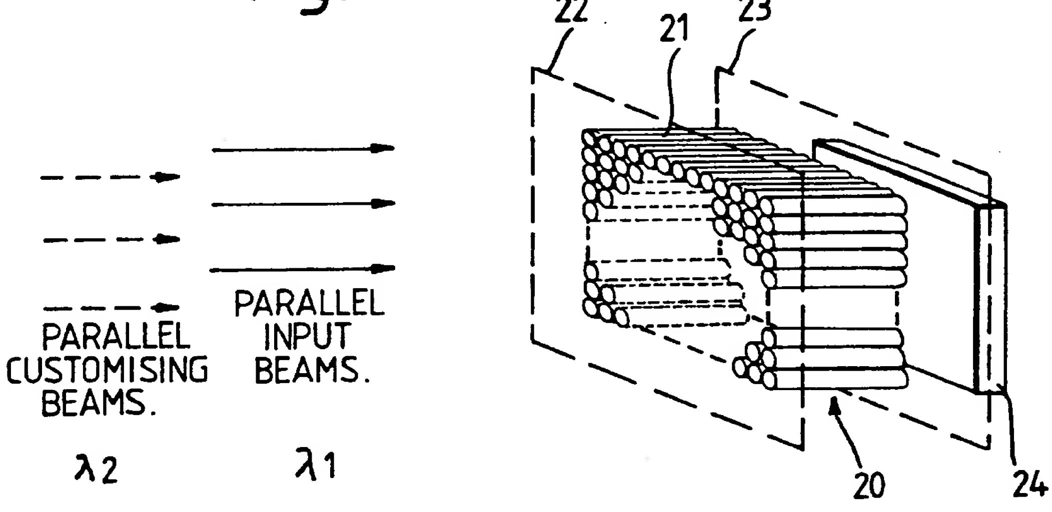
(54) Optical logic

(57) A two-dimensional optical logic gate array (20) is comprised by a plurality of polarisation-maintaining laser fibres (21), disposed between dielectric mirrors (22), (23). Each fibre of the array is in use associated with a respective customising beam (λ_2) and a respective signal beam (λ_1), which customising beams are capable of pumping the fibres and cause Kerr effect rotation of the polarisation of the respective signal beams whereby when a fibre is so pumped its output is changed accordingly. The array operates at very high speed with high parallelism, with minimal cross-talk and diffusion. In addition amplification is available in each fibre if the pump signal is sufficient to trigger lasing in the fibre.

Fig. 5.



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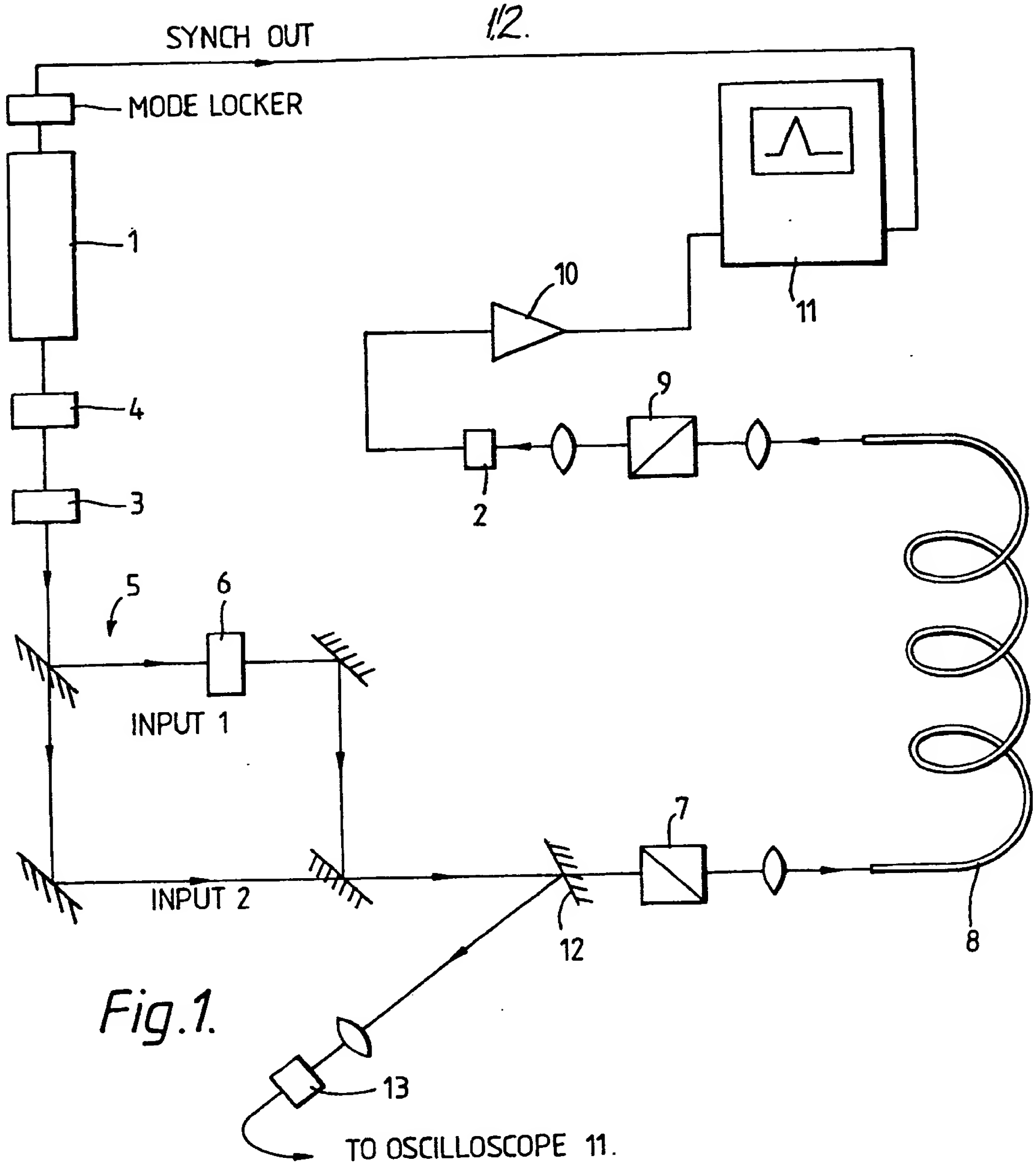

Fig.1.

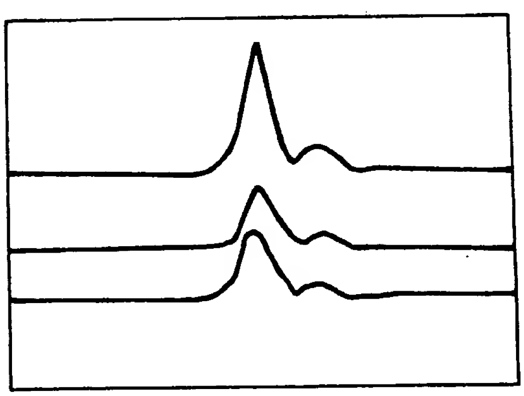

Fig.2.

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Fig. 3.

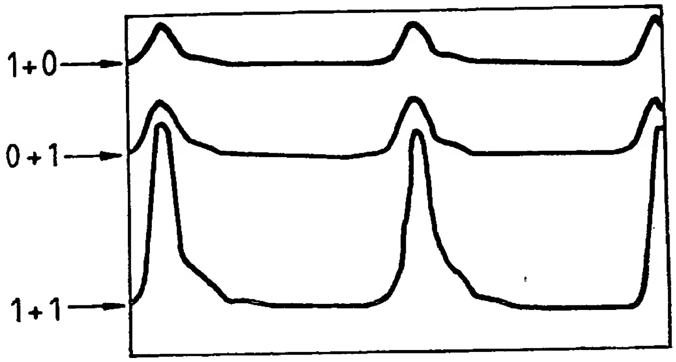


Fig. 4.

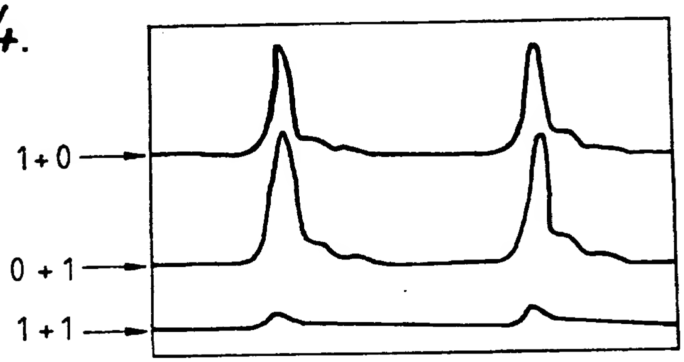
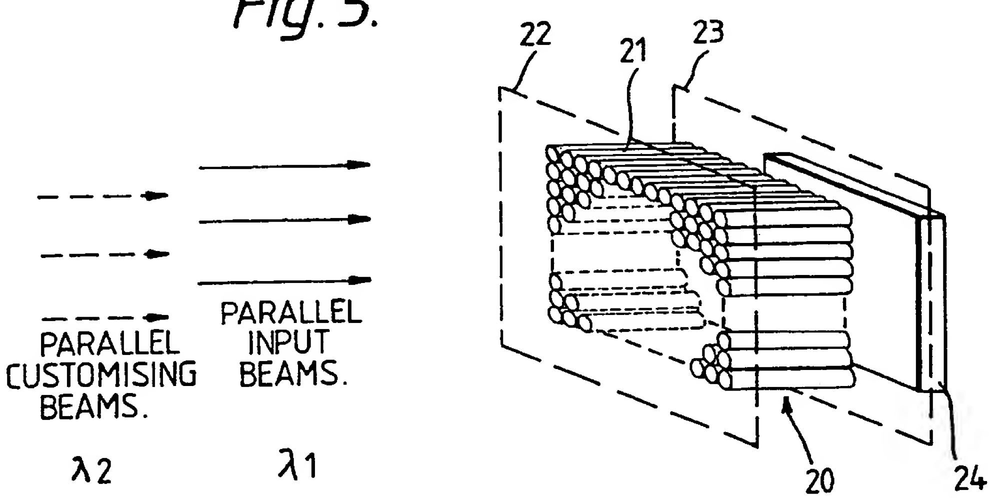


Fig. 5.



SPECIFICATION

Optical logic

This invention relates to optical logic and in particular to a two-dimensional optical logic gate array.

Progress in digital optics is highly dependent on the development of optical logic gates that are fast, have a low switching energy, a high contrast between the "ON" and "OFF" states and may be integrated into a two-dimensional array. Many devices have been developed which exhibit some of these requirements, for example, multiple quantum well devices and interference filters. These devices, however, have speed limitations owing to the nature of the non-linear mechanisms on which they are based. The multiple quantum well devices have recombination times of a few nsec whereas the interference filters have thermal recovery times of a few μsec.

To realise the full potential of digital optical techniques their high speed advantage over electronic systems should be exploited. The most promising non-linearity to achieve this is the Kerr effect, where response times, both rise and fall times, on the subpicosecond scale are possible.

The optical power for significant Kerr-effect switching in bulk materials is prohibitively high, but in waveguide devices having a small cross-sectional area and longer interaction the power can be reduced to practical levels.

According to the present invention there is provided a two-dimensional optical logic gate array comprised by a plurality of polarisation maintaining laser fibres.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:-

Figure 1 illustrates schematically an arrangement of apparatus employed to demonstrate the ability of polarisation maintaining optical fibre to act as optical logic gates;

Figure 2 illustrates the one set of traces obtained from the apparatus of Fig. 1;

Figure 3 illustrates traces obtained for the apparatus of Fig. 1 when the latter is operated to provide an AND gate;

Figure 4 illustrates traces obtained for the apparatus of Fig. 1 when the latter is operated to provide an XOR gate, and

Figure 5 illustrates schematically an embodiment of a two-dimensional optical logic gate array, comprised by polarisation maintaining laser fibres, according to the present invention.

We have previously shown GB Patent Application No. 8333609 (Serial No. 2151805A) (K.C. Byron 4) that the optical Kerr effect can be employed in optical fibres to produce optical switching and optical logic functions. An optical element was comprised by a length of polarisation-maintaining optical fibre and by means for launching a pump signal into the fibre in order to introduce birefringence therein. The amount of birefringence varies with the pump signal intensity. When a polarised signal is also launched into the fibre it is affected by the induced birefringene. The polarised signal will vary in transmission in accordance with the effect of the induced birefringence, and in the extremes will be fully on or off (switched on or off) and comprise an optical switch or optical logic element.

It has also been demonstrated by Ken-ichi Kitayama et al (Appl.Phys.Lett. 46(4) 15 February 1985) that a logic "AND" gate function at a speed of around 200 nsec can be achieved with an optical fibre based on Kerr-induced rotation of polarisation. Kitayama et al employed a 11 metre length of birefringent single mode fibre having an elliptical core (polarisation maintining) for their demonstration. Such a length of fibre means that the fibre-optic logic gate of Kitayama et al is more suitable for serial operations in data handling operations than parallel operations.

Using the Kerr effect in polarisation maintaining an non-polarisation maintaining fibre we have also demonstrated optical logic AND gates and XOR gates, at 1.06μm, but operating at considerably higher speeds (three orders of magnitude greater) than Kitayama et al, that is around 200 psec, and with a switching energy of around 10pJ. However once again this required long lengths of fibre, the experiments being performed with 3 metre and 200 metre lengths, which, once again, are not suitable for practical parallel operation.

The experimental arrangement we employed is shown schematically in Fig. 1. An Nd:YAG laser 1 emits a mode-locked pulse train at 1.06μm having a detector limited pulse width at half maximum height of 230 psec. For an optimum mode-locked condition the actual pulse width is 120 psec for this laser but the 100 psec rise and fall time of detector 2 prohibited an accurate measurement of this width. The vertically polarised output from the laser 1 was changed into circular polarisation on transmission through quarter wave plate 3. The laser beam is also passed through an attenuator 4. The attenuated and polarisation changed beam is split into two at 5 to provide the gate inputs (INPUT 1 and INPUT 2). One of the beam paths contains another attenuator 6 to adjust for equal power in both beams. The two beams are then recombined and after transmission through a linear polariser 7 are focussed on to the end of a polarisation maintaining fibre 8.

In one experiment the fibre 8 was 200 metres long and of a bow-tie design which maintained the polarisation state of the lowest order mode at 1.06μm with a loss thereat of 6dB/Km.

The polariser 7 was rotated such that the pulses were launched only into one of the

preferred polarisation states of the lowest order mode. At the output of the fibre 8 another polariser 9 was arranged such that at low input intensities the transmitted light incident on an 0.5 nsec risetime Germanium avalanche photodiode, comprising detector 2, was blocked. The detected pulses were amplified in amplifier 10 before display on a 1GHz real time oscilloscope 11. In order to ensure there were no non-linear effects in the detector and no feedback problems into the laser, a beam splitter 12 was used to direct a small fraction of the incoming light onto a second detector 13 at the fibre input.

The "AND" gate was demonstrated by first adjusting the power in the first attenuator 4 to a low level and ensuring that the transmission through the output polariser 9 was at a minimum. By alternately blocking one or other of the input beams (INPUT 1 and INPUT 2) and then blocking neither, it was observed that the output of the fibre was equal to the sum of both inputs i.e. no gating. The power was then increased and the procedure repeated it was observed that the net output when both beams were on, was greater than the sum of the two separate combinations when one is on and the other off. Although the output was not truly zero when either beam was on and the other off, for optimised alignment there is about 10dB extinction ratio between the output off and on state. The traces obtained in this case are shown in Figs. 2 and 3, Fig. 2 being the input signals and Fig. 3 the gated output. The shuttering effect produced by the intensity dependent polarisation rotation is seen in the cleaned up trailing edge of the bottom trace of Fig. 3.

The "XOR" gate function was observed by adjusting the power such that when either of the inputs was on and the other off, a high transmission through the output polariser 9 was seen. When both inputs were on, the induced polarisation rotation misaligned the fibre output polarisation direction with that of the output polariser. The traces for this gate operation are shown in Fig. 4. The extinction in this case was 15dB. The time/division on Fig. 2 was 1 nsec and that for Figs. 3 and 4, 2 nsec.

Further experiments were performed first on a 3 metre length of the same fibre and then on a 3 metre length of non-polarisation maintaining fibre. In the first 3 metre fibre it was found that the output polariser 9 was not required to observe the gating function (this also applied to the longer length) though the extinction ratio was not as great. It was also possible to obtain switching with the second 3 metre fibre, though here the output polariser was necessary.

These experiments demonstrated that very high speeds are obtainable with optical techniques. Moreover, another two orders of magnitude increase in possible, i.e. one or two picoseconds, before the Kerr effect would limit the response. The power to induce the polarisation rotation in these gates has been measured and is in the region of 50mW peak for the 200 metre length, thus it is quite reasonable to expect that these experiments could be performed with mode-locked semiconductor lasers.

A device termed a fibre laser plate has previously been proposed by Atsuya Seko et al (Appl. Optics Vol. 18, No. 12. 15 June 1979) for optical parallel processing. The fibre laser plate consists of many fibre laser (Nd-doped fibre lasers) bundled together to form a plate in a form similar to an optical fibre plate. The plate may be some 8 to 10mm thick and can emit a laser light image by means of two-dimensional end pumping over the face of the plate. When light with the wavelength in the absorption band of the laser glass excites the fibre laser plate through an input transparency, fibre lasers in the area corresponding to the input image are lased, assuming the threshold excitation energy is exceeded, and a laser image is emitted from the plate at a wavelength different from that of the pumping light and with high directionality. Atsuya Seko subsequently demonstrated (Appl.Phys.Lett. 37(3) 1 August 1980) that the fibre laser plate could be used as an optical switch array for all-optical parallel digital logic operations, such as A/D conversion and AND or OR operation. Whereas the switching times are fast (being determined by the laser fluorescent lifetime and of the order of μsec) and the switching energy low, ideally even faster switching times are required.

The present invention is based on the realisation that a very fast two-dimensional optical logic gate array can be achieved by means of a parallel array of fibre lasers having polarisation-maintaining properties and employing the Kerr effect. In particular low threshold single mode fibre lasers which have an interaction length for Kerr effect non-linearities considerably reduced in comparison with fibre may be used, thus facilitating formation or arrays since only very short fibre laser lengths, of the order of a few centimetres, are required. Thus an array in which the Kerr effect is employed to produce the requiste switching is proposed, which switching is achievable at the highest possible speed in comparison with other optical non-linearities, whilst at the same time providing the high parallelism required for optical signal parallel processing.

A two dimensional optical logic gate array according to an embodiment of the present invention is illustrated schematically in Fig. 5. It comprises a closely packed array 20 of polarisation maintaining doped laser fibres 21, for example Nd doped. The laser fibres may be standard GeO_2 doped SiO_2 fibre but polarisation maintaining and also doped with Nd_3. The polarisation maintenance may be due to employ-

ing a "bow-tie" fibre design. The fibres of the array are bundled together to form a plate and may be disposed in a frame-like holder (not shown) to maintain its structure. The fabrication of the fibre array may involve similar techniques to those employed for fibre face plates for image intensifiers, for example. At each end of the plate (array) is disposed a respective dielectric mirror 22 and 23. The input mirror 22 transmits pumping light and signal light and reflects lasing light entirely, whereas the output mirror 23 transmits only a very small proportion of lasing light. For each laser fibre 21 there is required a respective pulsed customising beam for pumping purposes, each fibre also having a respective input (signal) beam. Thus for the array 20 of laser fibres parallel customising beams at wavelength λ_2 are required together with parallel input beams at wavelength λ_1. The pump and signal wavelengths, λ_2 and λ_1 respectively, may be different ($\lambda_2<\lambda_1$) and separated at the output of the array by a filter 24. The pump and signal beams may both be produced by semiconductor laser arrays (not shown). Arrays of point sources can alternatively be produced corresponding to the fibres in the laser fibre arrays by holographic means. As mentioned above the laser fibres may be short in length so that the array 20 is of the order of a few centimetres in length, making it particularly applicable for parallel processing of optical signals in an optical computer.

When a laser fibre of the array is longitudinally pumped by a respective pulsed pump signal of suitable power, that laser fibre is caused to have an output which in view of the Kerr effect has its polarisation rotated in comparison with that of the input signal applied thereto. Since the laser fibre is polarisation maintaining a "switched" fibre, that is one to which the pump signal was applied, can be clearly distinguished from an "unswitched" fibre.

By virtue of the use of polarisation-maintaining laser fibres in the logic array not only can switching be achieved but also amplification if the pump signal is sufficient to trigger lasing in the fibre.

Apart from the advantages of high speed, high parallelism and the availability of amplification as mentioned above, the arrays of the present invention also have the advantages of minimal crosstalk and minimum diffusion, both of which can cause problems in other devices.

CLAIMS

1. A two-dimensional optical logic gate array comprised by a plurality of polarisation maintaining laser fibres.

2. An array as claimed in claim 1 wherein the laser fibres are single mode low theshold fibres.

3. An array as claimed in claim 2 wherein the fibres are neodymium doped.

4. An array as claimed in any one of claims 1 to 3, the fibres being bundled together and formed into a plate, dielectric mirrors being disposed at the input and out ends thereof.

5. An array as claimed in any one of the preceding claims in combination with means for providing a respective customising beam for each fibre and means for applying a respective signal beam to each fibre, which customising beams are capable of pumping the fibres whereby to induce Kerr effect rotation of polarisation of the respective signal beams whereby when a fibre is so pumped its output is changed accordingly.

6. An array as claimed in claim 5, wherein the customising beams and the signal beams are at differenct wavelengths, and including a filter at the array output for separation thereof.

7. An array as claimed in claim 5 or claim 6 wherein a signal beam is also amplified whilst transmitted through its respective fibre.

8. A two-dimensional optical logic gate array substantially as herein described with reference to and as illustrated in Fig. 5 of the accompanying drawings.

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